Development and Application of Adjoint Models and Ensemble Techniques

Ronald M. Errico
Global Modeling and Assimilation Office
Code 900.3, Goddard Space Flight Center
Greenbelt, MD 20771
phone: (301) 614-6402 fax: (301) 614-6297 email: rerrico@gmao.gsfc.nasa.gov

Grant Number: N00014-0310554
http://www.dao.gsfc.nasa.gov

LONG-TERM GOALS

This proposal covers some broad topics that are of mutual interest to scientists at the Goddard Earth Science and Technology Center (GEST), the Global Modeling and Assimilation Office (GMAO) at NASA, the University of Innsbruck, Austria, and the Marine Meteorology Division of the Naval Research Laboratory. These concern problems related to numerical weather prediction, particularly the use and evaluation of initial data and the estimation of forecast and analysis uncertainty. Since specific analysis techniques are constantly being modified and eventually replaced, a goal is to distinguish what is fundamental from what is transitory, so that the work has long-term applications. The support provided by ONR augments work being performed at GEST and allows continuation of extensive collaborations between the P.I. and staff at these other institutions, particularly NRL.

OBJECTIVES

Research objectives for the term of this proposal include aspects of data assimilation, singular vector analysis, and more general adjoint model development and applications. The work is being coordinated with NRL staff so as to augment, rather than duplicate, what is being done by them. The emphasis at GEST will be on fundamental aspects of the problems, including, but not limited to: parameterization of model Jacobians for efficient and effective tangent linear and adjoint calculations, evaluation of candidate ensemble forecasting systems, determination of the characteristics of proposed ensemble Kalman filter data assimilation techniques, and utilization of observation system simulation experiments (OSSEs) as a diagnostic tool for data assimilation.

APPROACH

The primary tools to be employed include: the Mesoscale Adjoint Modeling System (MAMS2, Errico et al. 1994; Errico and Raeder 1999), the U.S. Navy Operational Global Atmospheric Prediction System (NOGAPS; Hogan et al., 1999), NASA's Finite Volume General Circulation Model (FVGCM, Lin and Rood 1997) and its accompanying Data Assimilation System (FVDAS). This variety reflects the collaboration between the P.I. and colleagues at NRL and the GMAO. The different systems will be used as each may be particularly appropriate to a question examined and also to investigate the generality of results obtained.

A new model is also being developed by Martin Ehrendorfer (University of Innsbruck, Austria) and the P.I. This is a global, spectral quasi-geostophic model with much higher vertical and horizontal

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 2003		**00-00-2003 to 00-00-2003**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Development and Application of Adjoint Models and Ensemble Techniques	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Global Modeling and Assimilation Office,,Code 900.3, Goddard Space Flight Center,,Greenbelt,,MD,20771**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**5**	

resolution than the older one used extensively at NRL Monterey (e.g., Reynolds and Errico 1999). It is intended to allow explicit application of an extended Kalman filter and calculation of a complete spectrum of singular vectors. It is tuned to replicate both stationary and transient components of atmospheric energy spectra.

Other sets of necessary tools are also being developed. One set includes adjoint and tangent linear versions of the FVGCM and FVDAS. Another set includes numerical analyzers of very simple equations describing sampling problems encountered by ensemble data assimilation techniques. The latter are designed to give unambiguous results for a wide range of parameters. A third set includes algorithms for generating realistic initial condition errors for basic predictability studies with both NOGAPS and FVGCM. The last requires development of algorithms for spherical harmonic transforms on a global computational D-grid.

WORK COMPLETED

A paper has been submitted (Errico et al. 2003) describing the calculation of singular vectors for moisture-measuring norms. This was performed with MAMS. Norms included analysis error variance weighted specific humidity at the initial time and precipitation at the end time. Results with these norms were contrasted with those using the more common total energy norm applied at either initial or final times and an analysis error variance weighted norm for the dry fields applied at the initial time.

A 9-level version of the QG model, triangularly truncated at wavenumber 63 (T63L9 resolution) has been developed. This is forced by relaxation toward a January mean state and damped by linear diffusion. Forcing and damping parameters have been tuned to yield a k^{-3} inertial range with a realistic partitioning between kinetic and available potential energies and stationary and transient components. A manuscript documenting the model is being prepared.

Development and testing of an analysis-error simulator for creating initial model perturbations have continued. In particular, initial imbalances have been examined. These include imbalances related to geostrophic adjustment as well as to dynamic damping towards the model attractor. A manuscript describing this perturbation technique is being prepared.

Software for performing spherical harmonic transforms on the global computational D-grid for scalar fields has been developed and tested. It uses the generalized approach developed by Swarztrauber and Spotz (2000) for determining the latitudinal weights required for exact transforms.

A paper has been submitted to the Bulletin of the American Meteorological Society describing some basic characteristics of forecast error growth due to initial condition errors in numerical weather prediction models (Baumhefner and Errico, 2003). It corrects several common misconceptions about such error growth, including the rapidity and scale characteristics of such growth.

RESULTS

The most noteworthy result reported in Errico et al. (2003) is that initial moisture errors can create as large forecast wind errors as initial errors of either temperature or wind fields, when either initial error is consistent with analysis uncertainty. Furthermore, there are cases in which optimal temperature and

moisture perturbations independently produce the same wind perturbations. This appears to concern the fact that both are related to moist specific enthalpy.

Although the spherical harmonic transform software for scalar fields performs as intended, that for the vector fields requires twice as many latitudinal points as the maximum order of the Legendre polynomials for zonal wavenumber 1. It also requires an additional pair of transforms for zonal wavenumber 1. It therefore appears that further attention to conditions on the latitudinal weights for the vector transforms is required.

The new analysis error simulator behaves as intended. Although several adjustments are performed on the original spectrum, the properties designed into the original perturbations appear generally preserved well. In particular, altering the horizontal power spectrum from white to red does not seem to significantly disturb the locally defined variances or vertical correlations. Furthermore, the NOGAPS non-linear normal mode initialization scheme does not greatly affect the perturbation spectra except for those of the divergence field. A remaining concern is that total perturbation energy initially decays, recovering its initial value only after 1 day. It is unclear how appropriate this behavior is.

IMPACTS/APPLICATIONS

The new T63L9 quasi-geostrophic model will be particularly useful for examining numerical weather prediction and data assimilation questions related to the basic non-modality of forecast errors. The size of its state vector is sufficiently large to reflect atmospheric complexity but still small enough to allow computation of a full-extended Kalman filter.

The new perturbation technique now installed at NRL still requires some tuning, especially regarding its consistency with the statistics of reanalysis differences. The behavior of these as initial perturbations in forecasts also needs further examination. Most notably, initial moisture perturbations are as yet absent, and therefore require implementation. Design of those perturbations must include consideration of constraints on relative humidity.

The new spherical harmonic transform software will be used in several applications for both the FVGCM and FVDAS. First among these will be a parallel development of the NRL analysis error simulator for the FVGCM grid. Second will be development of normal mode projection software for the D-grid. The spectra software will also be used to define a filtered norm for the computation of FVGCM singular vectors.

TRANSITIONS

The analysis error simulator will be transitioned to FNMOC as an initial-condition perturber for a next-generation operational ensemble forecasting system once further testing is completed.

The spherical harmonic transform software will be transitioned to the GMAO at NASA once the transform for the vector wind components performs better.

The T63L9 quasi-geostrophic model will be transitioned to the University of Innsbruck for use by students in assorted projects.

RELATED PROJECTS

The National Science Foundation has been asked to fund the P.I. on a project to examine the implications of non-modality on ensemble forecasting and data assimilation.

NASA is funding several projects related to adjoint model development, singular vector analysis and applications, data assimilation, and observation system simulation experiments, of which the P.I. is a collaborator.

REFERENCES

Errico, R.M. and K.D. Raeder, 1999: An examination of the accuracy of the linearization of a mesoscale model with moist physics. *Quart. J. Roy. Meteor. Soc.*, 125, 169-195.

Errico, R. M., K. Raeder, and T. Vukicevic, 1994: *Mesoscale Adjoint Modeling System Version 1.* NCAR Technical Note. NCAR/TN-410+IA, 224pp.

Hogan, T. F., T. E. Rosmond, and R. L. Pauley, 1999: The navy operational global atmospheric prediction system: recent changes and testing of gravity wave and cumulus parameterizations. *Preprints, 13th Conf. Numerical Weather Prediction,* Denver, CO, Amer. Meteor. Soc., 60-65.

Lin, S.J., and R.B. Rood, 1997: An explicit flux-form semi-Lagrangian shallow-water model on the sphere. *Quart. J. Roy. Meteor. Soc.*, 123, 2477-2498.

Reynolds, C., and R. M. Errico, 1999: On the convergence of singular vectors toward Lyapunov vectors. *Mon. Wea. Rev.* 127*,* 2309-2323.

Swarztrauber, P.N., and W.F. Spotz, 2000. Generalized discrete spherical harmonic transforms. *J. Comp. Phys.,* 159, 213-230.

PUBLICATIONS

Baumhefner, D. P., and R. M. Errico, 2003: The nature of intrinsic predictability for synoptic scale flow. *Bull. Amer. Meteor. Soc.*

Errico, R. M., K. D. Raeder, and M. Ehrendorfer, 2003: Singular vectors for moisture-measuring norms. *J. Roy. Meteor. Soc.* [in press, refereed].